PERFORMANCE OF A CIRCULAR BODY EARTH-TO-ORBIT WINGED TRANSPORT WITH VARIOUS STRAP-ON BOOSTERS

Ian O. MacConochie
J. Chris Naftel
Frederick W. Widman

October 1988

NASA

National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23665

Performance of a Circular Body Earth-to-Orbit Winged Transport

With Various Strap-on Boosters

by

Ian O. MacConochie, J. Chris Naftel, and Frederick W. Widman

Abstract

Various types of twin strap-on boosters have been evaluated by applying them to a core vehicle. The core vehicle has a clipped delta wing and a simple circular body, and is equipped with five Space Shuttle main engines. The only propellants in the core vehicle are liquid oxygen and liquid hydrogen. The strap-on boosters investigated include the current Shuttle solid rocket motors with steel cases and advanced solids with graphite composite filament-wound cases. Also, two types of liquid-oxygen/hydrocarbon boosters were investigated - one pair without crossfeed to the core vehicle and one with. The payloads obtained were tabulated for various assumptions, such as power levels on the core vehicle engines, number of engines, and maximum allowable flight dynamic pressures. The payload for the core vehicle with two filament-wound Shuttle solid rocket strap-on boosters was 83,000 lb and the payload for two liquid strap-ons with crossfeed was 84,000 lb. The core vehicle with Shuttle solid rocket strap-on boosters is regarded as a near term technology system.

INTRODUCTION

In conceptual vehicle design studies, it is customary to identify a mission and size to the vehicle for this mission. In this study, however, the core vehicle, the core vehicle engines, the strap-on solids, and the hydrocarbon engines on the strap-on liquids were held constant while the payload delivered to orbit was allowed to vary. An advantage of this approach is that existing hardware can be considered without the risk of optimizing a vehicle that has fractional subsystems. A major fixed subsystem element of concern in this study that must not be fractional is the current Space Shuttle Main Engines (SSME). Another advantage in allowing the payload to vary on a well-established set of subsystems is that less attention is required in regard to packaging, as the vehicle is allowed to vary in size for different payloads. The approach may not be suitable when the primary goal is to size a vehicle for a given mission, but it is revealing in ascertaining the effects on payload of such changes as power level for the main engines for a system made up of existing or point design subsystems or the effect of crossfeed on payload deliverable. In figure 1, the launch systems studied are compared with the Shuttle.

VEHICLE-SYSTEMS DESCRIPTIONS

Core Vehicle

The vehicle used as a core stage in these studies is similar to the single-stage dual-fuel design described in reference 1. However, the hydrocarbon fuel and hydrocarbon engines have been removed. Also, instead of three SSME's and the dual-fuel design, five SSME engines were assumed. The result is a core vehicle having a gross weight of 2,450,000 lb for the strap-on booster applications in lieu of 4,870,000 lb for the dual-fuel single-stage design. The substantial reduction in gross weight is due to the removal of the much denser hydrocarbon fuel from the system. The cargo, as in the reference vehicle, is carried in a space between the fuel and oxidizer tanks. The space provided is 30 ft in diameter by 15 ft long. Also, from the original design, the customarily used pilot's canopy has been eliminated in the interest of weight savings. In its place, a nose-gear-deployed TV camera is supplied to provide the pilot with forward visibility for landing. Three flush-mounted circular viewing ports 4 ft in diameter are provided. The crew can see the side of the runway out of a side-mounted port. For ferry, two 747 engines, rated at 56,700 lb thrust each, are attached to the vehicle (Fig. 2). This approach is necessary, since the vehicle is too big to ferry on any existing aircraft.

The vehicle is equipped with a dorsal fin and two tip fin controllers - the former device is used for directional control, and the latter devices are used for energy management during unpowered descent to landing. The subsonic characteristics of the dorsal fin for directional control have been reported in reference 2. The characteristics of the tip fin controllers for directional control and energy management have been reported in reference 3. The two devices have not been tested together as controls and are presented in concept only. The thrust-to-weight ratio for the core vehicle is 0.76. The core vehicle engines contribute 37.5 percent of the total launch vehicle thrust at liftoff. The value approximates that used for the current orbiter-external-tank combination. In selecting this relatively low thrust-to-weight ratio, compared with a value of 1.3 for a single stage, for example, the propulsion system mass is minimized on the core vehicle which provides a favorable center-of-gravity location for flight.

Solid Rocket Strap-ons

The solid rocket strap-ons investigated include the current Space Shuttle rocket motors (SRM's) with steel cases. The second set investigated are similar in shape and propellant loading to the current SRM's except that graphite filament composite cases are assumed giving a weight reduction of approximately 45 percent. The Shuttle solid rocket booster parachute recovery system is assumed. The sea level thrust produced by each solid is 2,650,000 lb. This value is assumed for both the current solids and the advanced filament wound cases.

The aft attachment points for the SRM's are located on the perimeter of the same thrust structure used for the core vehicle SSME's. These fittings react to axial (thrust) and radial loads, while the forward fittings react only to radial loads. During separation the SRM's are allowed to rotate away from the fuselage and wing through a small angle about the aft fittings prior to complete release. The plane of the rotation is midway between the plane of the wing and the side of the body. This is done in order to give adequate clearance between the core vehicle and the SRM's and to allow for uncertainities in tip off during booster separation.

Liquid Rocket Strap-ons

For the unmanned liquid strap-ons, photographic scaling of the core vehicle body was used; that is, the fuselages have the same body fineness ratios and ogive shapes (Figs. 3 and 4). Two liquid boosters were studied, one with a crossfeed of propellant to the core vehicle engines and one without. Each strap-on is equipped with three 625,000-lb sea level thrust hydrocarbon engines with hydrogen gas generators (Ref. 4). The same number and size of engines are used on both crossfeed and no crossfeed boosters.

For recovery, a pivoting high-aspect-ratio wing is used. This wing, referred to as an oblique wing, has been extensively studied and is being tested for possible future use on airplanes (Ref. 5). The wing is being proposed for this application because of its storability and variable sweep capability; the unswept configuration is particularly suitable for subsonic glide and landing. The oblique wing is located with its span along the axis of the booster with wing tips captured using a mechanical lock to prevent flutter during ascent.

At separation the mechanical locks are released using pyrotechnics and the wing is deployed in a highly oblique position. Simultaneously the wing pivot is driven to the trim position for the flight Mach number, wing angle, angle of attack, and center of gravity. The drive consists of an electrically operated worm screw turning in a nut assembly attached to the wing and guided by a channel mounted along the top centerline of the booster (Fig. 5). The wing could be continuously driven during flight as the method for trimming the vehicle. Pitch, yaw, and roll control are provided by the small dorsal and canards shown; and roll is controlled during subsonic flight by the movable surfaces shown on the wing. The body flap shown can be used to augment the trim capability provided by axial movement of the wing. In order to land both strap-ons, the final approach is extended for one, while the other lands and is diverted to a taxiway using nose wheel steering.

CORE VEHICLE AND BOOSTER SIZING

Normally, when configuring a new launch system, various weights and sizing routines are combined with aerodynamic programs to obtain weights. In the current study, a vehicle has been used for which some wind tunnel data are available for a given mass properties estimate (Ref. 2). The all-LOX/LH2-propulsion system on the vehicle weighs 49,500 lb compared with 51,900 lb for the original design having a mix of hydrogen and hydrocarbon engines. Because of this small difference in propulsion system weights and the other vehicle subsystems, the center of gravity changed little. This made it possible to apply the same wind tunnel results used for the dual-fuel version to the current core vehicle. For the all-LOX/LH2-propulsion system, SSME's were selected because they are already developed. Five such engines conveniently fit the 32.8-ft diameter base of the vehicle, provide a near optimal thrust-to-weight (T/W) value for the combinations of strap-on boosters considered, and (as stated above) impact the original mass properties of the original dual-fuel core vehicle little. Five engines on the core vehicle in combination with two SRM's give a launch vehicle thrust-to-weight ratio at lift-off of 1.44. This value for the present Shuttle = 1.43 at lift-off. Four engines instead of five on the core vehicle give a lift-off T/W of only 1.09. This latter value of T/W would yield an unreasonably large system because of the excessively large gravity losses from a low (non-optimum) initial T/W.

In order to obtain a preliminary size for the liquid boosters without cross feed, an inert weight fraction was assumed, and a 3-g limit at booster engine cutoff was assumed. The following equations were then used :

$$T/W = 3 = (T_c + T_s)/(W_c - tM_c + tM_s n)$$

where

T_c and T_s = Thrust of core vehicle and strap-on propulsion, respectively, lb
W_c = Liftoff weight of core vehicle, lb
M_c = Flow rate of propellant in core vehicle, lb/sec
W_s = Gross weight of strap-ons, lb
M_s = Flow rate of propellant in strap-on engines, lb/sec
n = Inert weight of strap-ons divided by propellant weight
t = Operating time of strap-ons, sec

The last (bracketed) term of the above equation is the system weight at booster engine cutoff or the core vehicle weight, less the core vehicle propellant depleted during strap-on booster operation, plus the estimated inert weight of the strap-ons. The equation is then solved for t. Using the value of t, the preliminary weight of the strap-on boosters is given by:

$$W_s = (1 + n)tM_s$$

For the strap-on boosters with crossfeed, the same size and number of hydrocarbon engines were used, but the body shells of the boosters were

enlarged geometrically to provide the extra volume required to accommodate the propellant to operate the core vehicle engines during strap-on booster operation. The resultant system has a higher gross weight by the amount of the crossfeed propellant and changes in booster inerts. Thrust-to-weight value at liftoff and staging were correspondingly lower, since the same number and size of hydrocarbon engines were used for both crossfeed and the no crossfeed cases.

For both liquid strap-on boosters, the propellant is off-loaded (and the body re-sized) to meet the Mach 3 staging velocity constraint for glideback return to launch site. For the solid strap-ons, no sizing was made since the propellant loading and other design aspects were fixed quantities.

Weights for the core vehicle and various strap-ons are summarized in Table I. Weights for the Shuttle with external tank are listed for comparison purposes. The T/W values for each stage are also listed. The T/W for the core vehicle (0.8) is not too different from that of the current Shuttle and external tank combination (0.6).

SYSTEMS PERFORMANCE

All of the following estimates of performance were made using the Program to Optimize Simulated Trajectories (POST) (Ref. 6). Each launch configuration performance was measured in terms of payload deliverable to a 50 X 100 nmi orbit. The payload is obtained by subtracting all the personnel, subsystem, and fluid weights of the core vehicle from the injected weight predicted by the POST Program. In figure 1, the systems analyzed are shown and compared with the current Shuttle. Detail weights of the core vehicle and the liquid strap-ons are given in the appendix in A-I through A-III. Details of the geometry of the core vehicle are given in Table A-IV.

Solid Rocket Strap-ons
    The payload for the core vehicle with solid rocket motor (SRM) strap-ons is 66,000 lb compared with the nominal 65,000 lb for the current Shuttle with a drop tank. The gross lift-off weight for the fully reusable core stage and two SRM's, is 5.0 Mlb, which is about half a million pounds greater than that for the current Shuttle. The addition of two SSME's, about 400,000 lb of propellant, and about 180,000 lb of structure represents part of the penalty to the core vehicle for full re-usability when compared with the Shuttle Orbiter External Tank (ET) combination. If the core vehicle had the same capabilities as the Shuttle Orbiter, the penalty would be even higher. These greater capabilities for the Orbiter include the ability to accommodate a crew of eight compared with two, and an 8-day stay on-orbit stay time versus 3 days for the core vehicle.

The payload for the system with the filament-wound SRM's is estimated to be 83,000 lb, this represents a 17,000 lb increase over the payload obtained when using the current SRM's with steel cases. The filament-wound cases are assumed to be 55 percent of the weight of the steel cases.

Liquid Rocket Strap-ons

The payload for two liquid boosters with no crossfeed is estimated at 28,000 lb. The payload for the two liquid boosters with crossfeed was found to be 84,000 lb. This payload gain is dramatic, but the increase is associated with much greater operational complexity - namely the connection and pressure testing of a crossfeed system. The core vehicle could be flown without crossfeed for the smaller (i.e. 28,000 lb) payload.

The thrust-to-weight ratio versus time histories are shown in figures 6 and 7 for the solid and liquid strap-ons, respectively. The difference in T/W between the SRM's with steel and filament wound cases is simply due to the 170,000-lb differences in SRM case weights (Fig. 6). The inflections in the curves in figure 6 in the vicinity of 50 seconds lapsed time from liftoff are the result of thrust tailoring of the cast propellant in order to reduce the wing loading for the current Shuttle near maximum dynamic pressure. The SSME's are also throttled during this period. This tailoring of the SRM thrust and throttling of the SSME's may not be necessary for the integral core vehicle with strap-on solids. The elimination of the period of thrust reduction could amount to an enhancement of payload capability for the core vehicle with strap-ons but has not been assumed in the performance figures shown. The nearly constant level of acceleration during the 75- to 100- second time period is again the result of tailoring of the SRM propellant grain. At approximately 300 seconds, it is necessary to start throttling engines on the two SRM configurations. At insertion, three engines give approximately a 3-g acceleration.

The effect on T/W of adding crossfeed propellant to the liquid strap-ons can be seen in figure 7. The decrease in T/W at lift-off and at booster engine cut-off (BECO) for the liquid strap-ons from the added weight of the cross-feed propellant is very evident. Lapsed time from lift-off to insertion is 475 seconds for the cross-feed version compared to 405 seconds for the no cross-feed case. Even with the somewhat lower thrust-to-weight at liftoff and staging and the higher gravity losses (i.e., longer flight time), the crossfeed strap-ons yield the much higher payload.

For comparison purposes a T/W profile is given for the current Shuttle (Fig. 8). The effects of flight dynamic pressure and engine power levels for the standard and filament-wound SRM's are shown in figure 9. The decrease in the slope of the curves for payload delivered at approximately 1100 psf suggests that the ascent trajectory should be limited to this value or less since payload gain is minimal for the higher allowable dynamic pressures. The apparent payload gains at the higher allowable flight dynamic pressure would be even less if the extra penalties for structure and TPS for the more severe flight enviroment had been included.

By allowing the engines on the core vehicle to operate at 109 percent of normal power level (NPL) compared with 10 percent, a gain of up to 2 percent in payload is obtained for both the standard and filament-wound SRM's (Fig. 9). By operating the core vehicle engines at 65 percent of NPL during parallel burn of the solids, the payload deliverable dropped by about 10 percent in comparison with operation of the engines at 104 and 109

percent during the entire ascent (lower set of curves in figure 9.) This mode of operation was investigated to determine if the payload delivered might be greater because of the conservation of propellants for post staging flight, but this was found not to be the case. By operating the core vehicle SSME's at 109 percent after staging of the solids, a 5-percent gain in payload was obtained over operating the engines for the same period at 104 percent.

The effect of numbers of core vehicle engines on payload was investigated (Fig. 10). Trajectories were run with four and six SSME engines and hypothetical cases of four and one-half and five and one-half engines. Based on these trajectory runs for a 104 percent power level on all engines, a five engine propulsion system is near optimal with a payload deliverable of 66,000 lb. With a four engine system a payload of 60,000 lb is deliverable (Fig. 10). If one engine is out on the five engine system, the payload deliverable is 50,000 lb. This figure is determined by subtracting 10,000 lb from the 60,000 lb shown for the four engine case (10,000 lb being the allowance for an inoperative engine and ancillary systems including pro-rated penalties for pressurization and feed system.)

EXPENDABLE CORE ALTERNATIVE

As an alternative version of the strap-on systems, the wings, landing gear, crew compartment, and other systems not necessary for an expendable system, could be removed from the core stage (Fig. 11). The estimated payload capability for this system is approximately 160,000 lb when the filament-wound SRM's or cross-feed liquid strap-ons are used. In order to minimize the cost of the conversion, the original ringframes are retained on the core vehicle. Closures are placed over the wing-root-to-body attachment point. Much of the high-temperature thermal protection system is also removed. The advanced carbon composite nose cap would be replaced with lower temperature (lighter and less expensive) titanium or high nickel alloy steels.

SUMMARY REMARKS

Several launch systems have been assessed that require a minimum of development in subsystem hardware. One such system consists of a core vehicle that utilizes five existing (SSME) LOX/LH2 engines with a boost stage that utilizes two existing SRM's. The estimated payload capability for this system is 66,000 lb. No major new technology developments are required. However, subsystem weights of the core vehicle and liquid strap-ons are included so that an assessment of the level of technology can be made element by element. Composites are used for the core vehicle body structure except for the propellant tanks which are aluminum. A 10 percent increase in weight is assumed over the current Shuttle tank weights to

allow for reusability. Other alternatives include the use of SRM's with filament-wound cases for a payload of 83,000 lb; or LOX/hydrocarbon strap-ons with crossfeed and glideback capability for 84,000 lb payload; the latter system requires a new liquid hydrocarbon rocket engine potentially making the liquid strap-on design more costly to develop. An expendable core stage with crossfeed liquids or SRM's can deliver an estimated 160,000 lb payload.

References:

1. MacConochie, Ian O. and Klich, Phillip J., "Technologies Involved in Configuring An Advanced Earth-to-Orbit Transport For Low Structural Mass." A paper presented at the 39th Annual Conference of the Society of Allied Weight Engineers, Inc, St. Louis, Missouri, May 12-14, 1980, SAWE Paper No. 1380.

2. Lepsch, R. A. and MacConochie, I.O. "Subsonic Aerodynamic Characteristics of Circular Body Earth-to-Orbit Transport." A paper presented at the AIAA 4th Applied Aerodynamics Conference, San Diego, Calif. June 9-11, 1986 Paper No. AIAA 86-1801-CP.

3. Powell, R. W.; and Freeman, D. C., Jr.: Application of a Tip-Fin Controller to the Shuttle Orbiter for Improved Yaw Control. AIAA Paper 81-0074, January 1981.

4. Luscher, W. P. and Mellich, J. A., "Advanced High Pressure Engine Study for Mixed-Mode Vehicle Applications" NASA CR-135141. January 1977.

5. Curry, Robert E., and Sim, Alex G., "In-Flight Total Forces, Moments, and Static Aeroelastic Characteristics of an Oblique-Wing Research Airplane. NASA Technical Paper 2224, Oct. 1984.

6. Brauer, G. L.; Cornick, D. E.; and Stevenson, R.: "Capabilities and Applications of the Program to Optimize Simulated Trajectories (POST) - Program Summary Document." NASA CR-2770, February 1977.

Table I. Launch Systems Weights

| Element | Weight, K lb | | | T/W** |
	At MECO*	Propellants	Gross	
Core vehicle	470	1920	2343	0.8
Shuttle solids (SRM's)	366	2232	2598	2.0
Shuttle solids (Filament wound cases)	201	2232	2433	2.1
Liquids without cross-feed	112	780	922	4.1
Liquids with crossfeed	172	11518	1690	2.1
Shuttle Plus External Tank	320	1630	1950	0.6

*Main engine cutoff

**T/W   Thrust of stage divided by weight of stage

197 ft

Shuttle solids

149 ft

Hydrocarbon liquid boosters (with crossfeed)

126 ft

Hydrocarbon liquid boosters (no crossfeed)

87 ft

TSLS = 2650 klb ea
$\varepsilon = 7.72$

5 SSME engines (typ)
TSLS = 375 klb ea
$\varepsilon = 77.5$

3 LOX/RP engines
TSLS = 625 klb ea
$\varepsilon = 50$

Payload, klb			
65	66/83*	84	28
Gross, Mlb			
4.5	5.0*/4.8	4.1	3.3
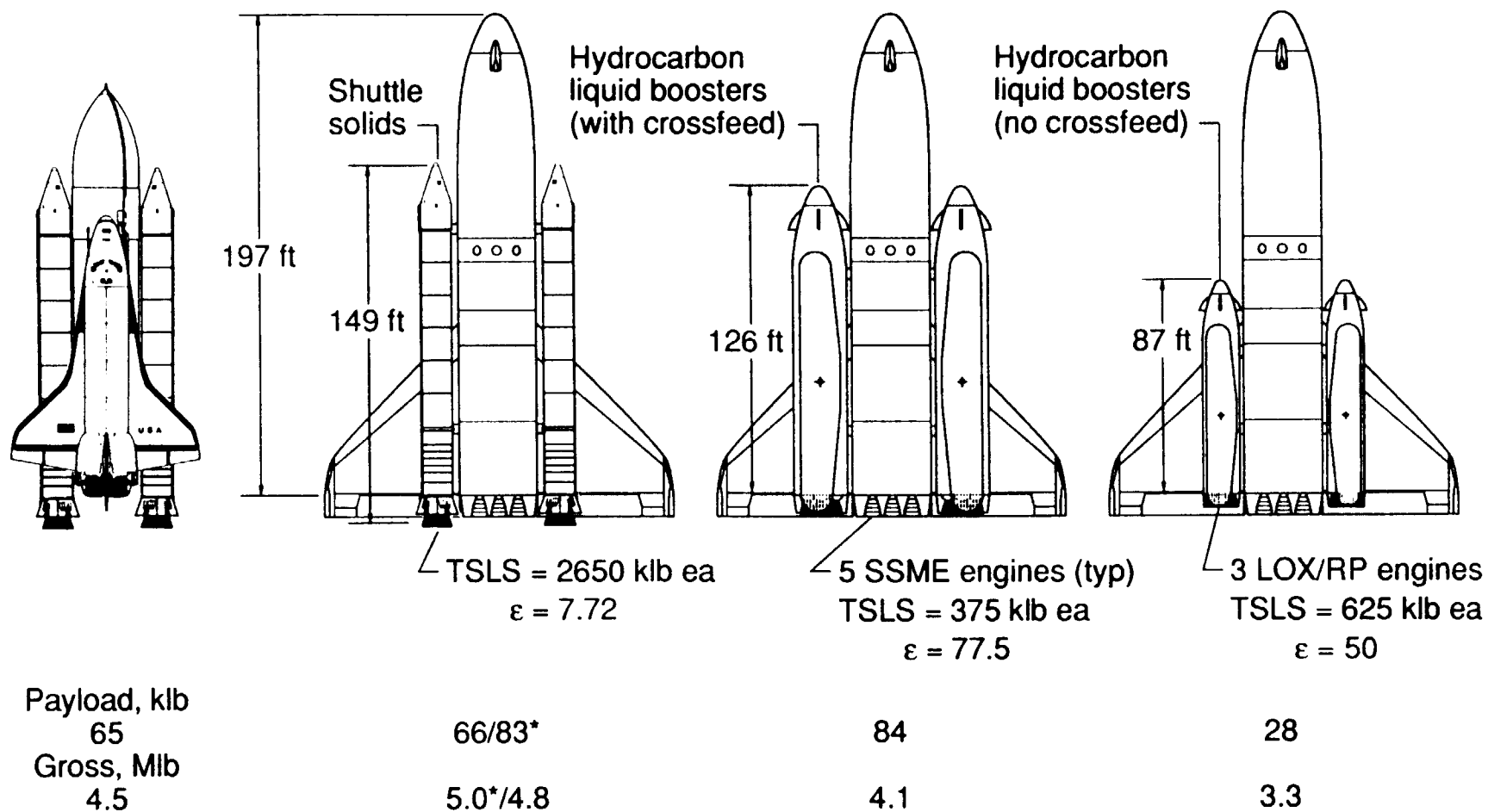
*Graphite filament-wound cases

Figure 1.- Size and weight comparisons for core vehicle with strap-ons.

LH$_2$

LOX

Two removable
747 engines
(57 klb TSLS
per engine)

Cruise weight at takeoff = 400 klb
(with 80 klb of jet fuel)

Crew   Cargo

Jet fuel
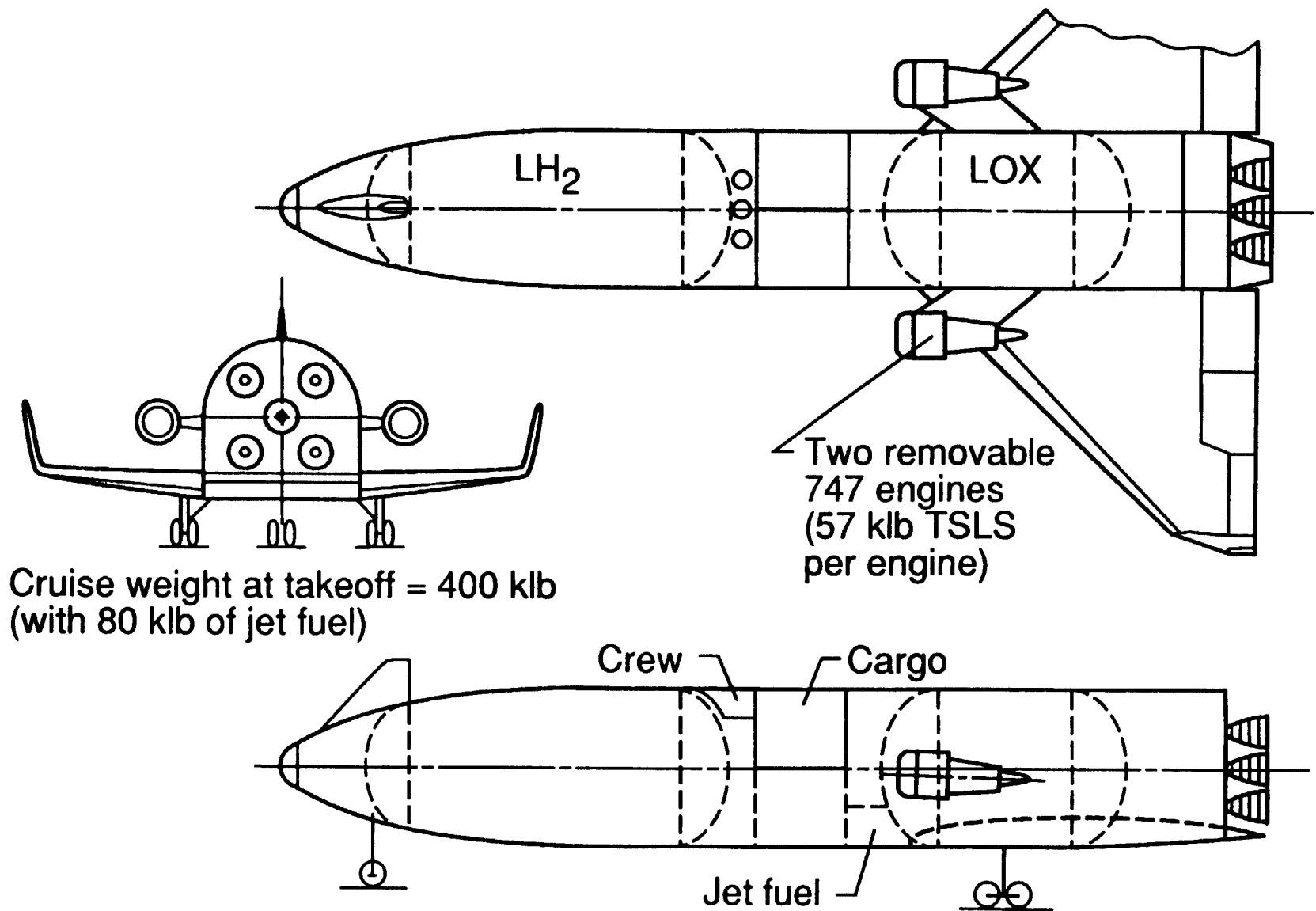
Figure 2.- Core vehicle with add-on airbreather engines for ferry.

Weight

Gross, klb   900

Landed, klb   82

126 ft

3 LOX/RP engines
with H_2 gas generators

$\varepsilon = 50$

TSLS = 625,000 lb

LOX   RP LH_2
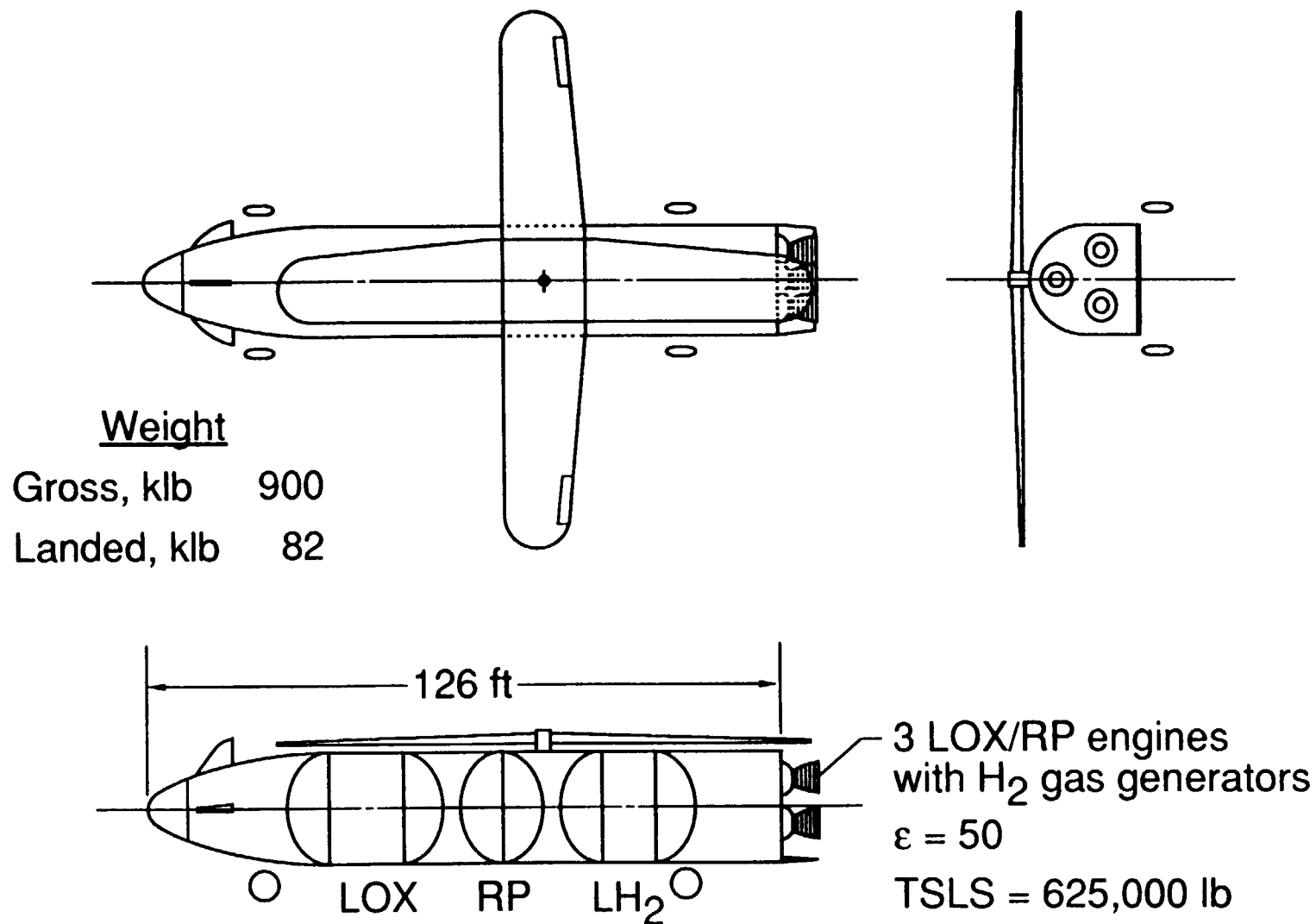
Figure 3.- Oblique-wing liquid strap-on sized for crossfeed.

Weight

Gross, klb   450

Landed, klb   60

$\leftarrow$———— 87 ft ————$\rightarrow$

3 LOX/RP engines
with H_2 gas generators

$\varepsilon = 50$

LOX   RP LH$_2$

TSLS = 625,000 lb
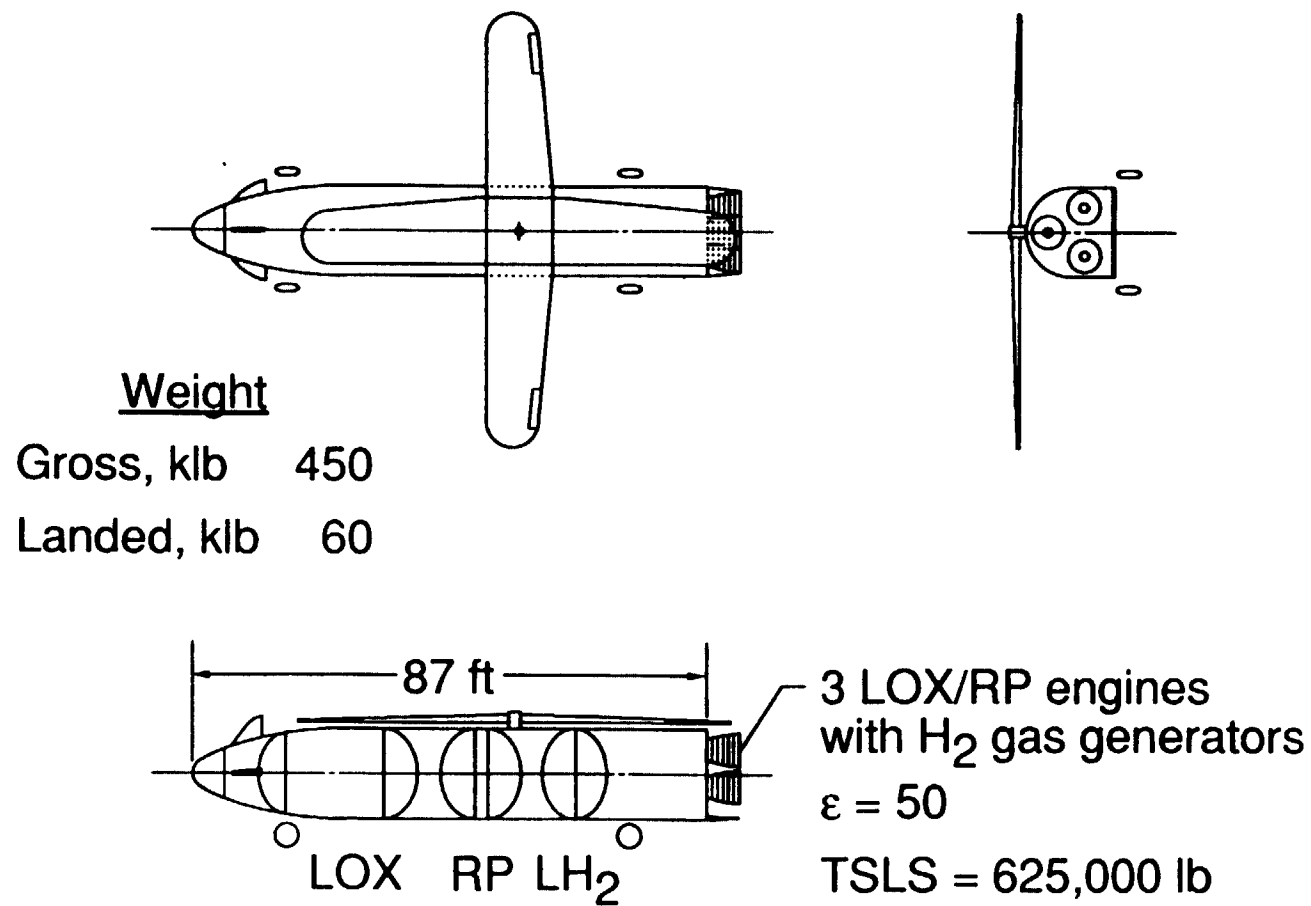
Figure 4.- Oblique-wing liquid strap-on without crossfeed
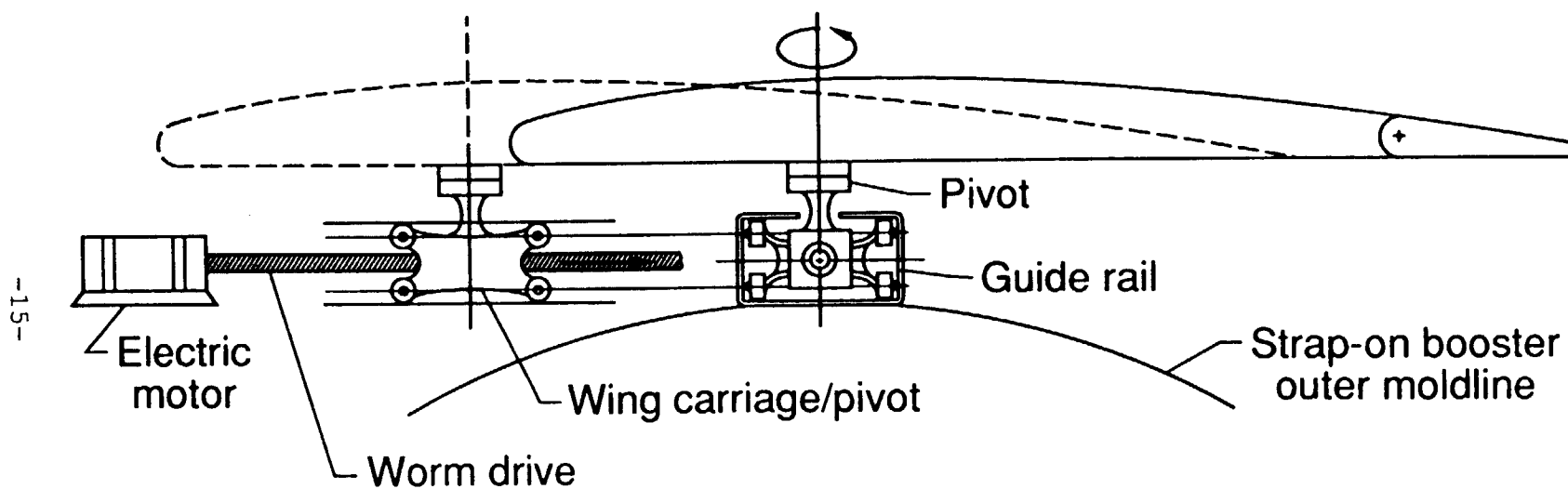
Figure 5.- Oblique wing attachment assembly.
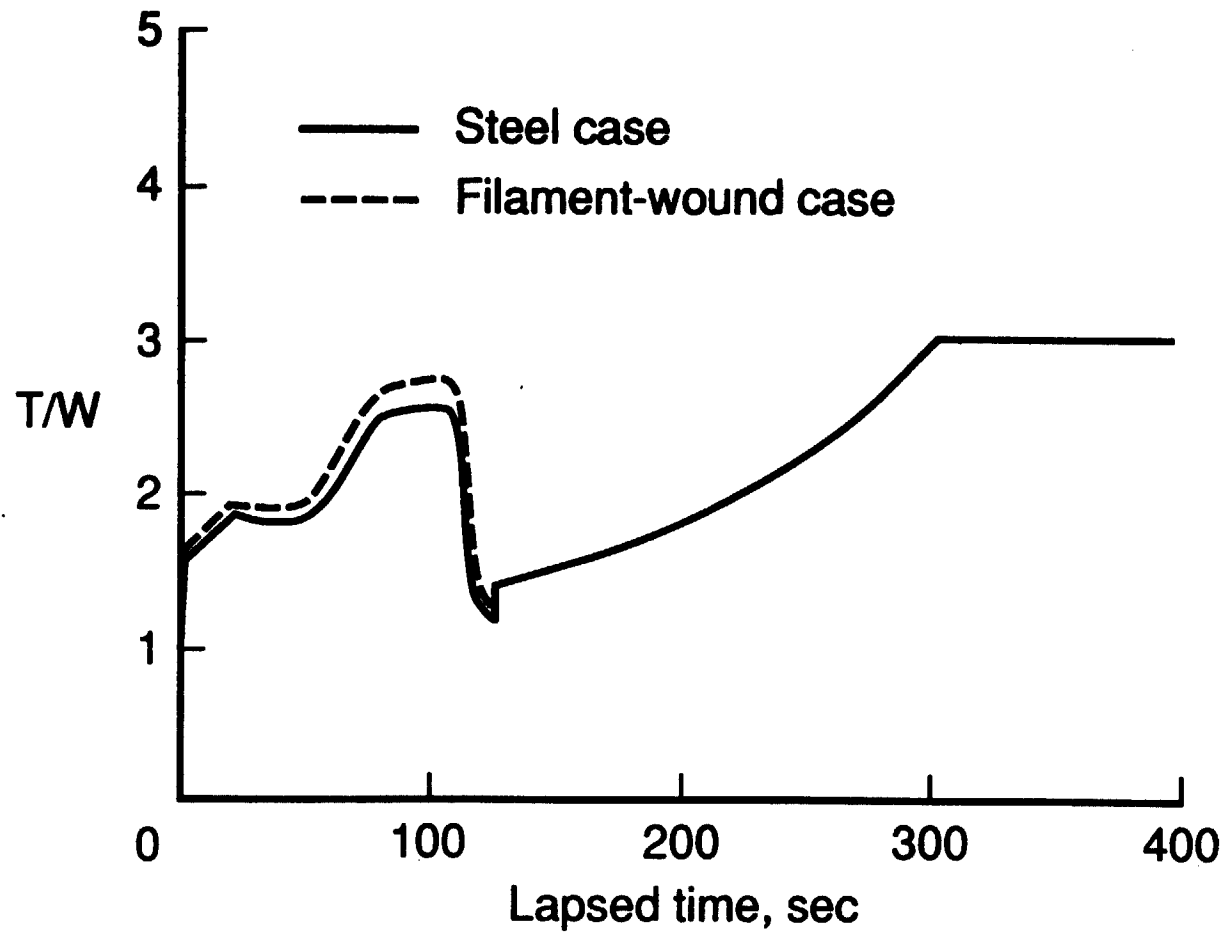
Figure 6.- Thrust-to-weight ratio for core vehicle with SRM's.
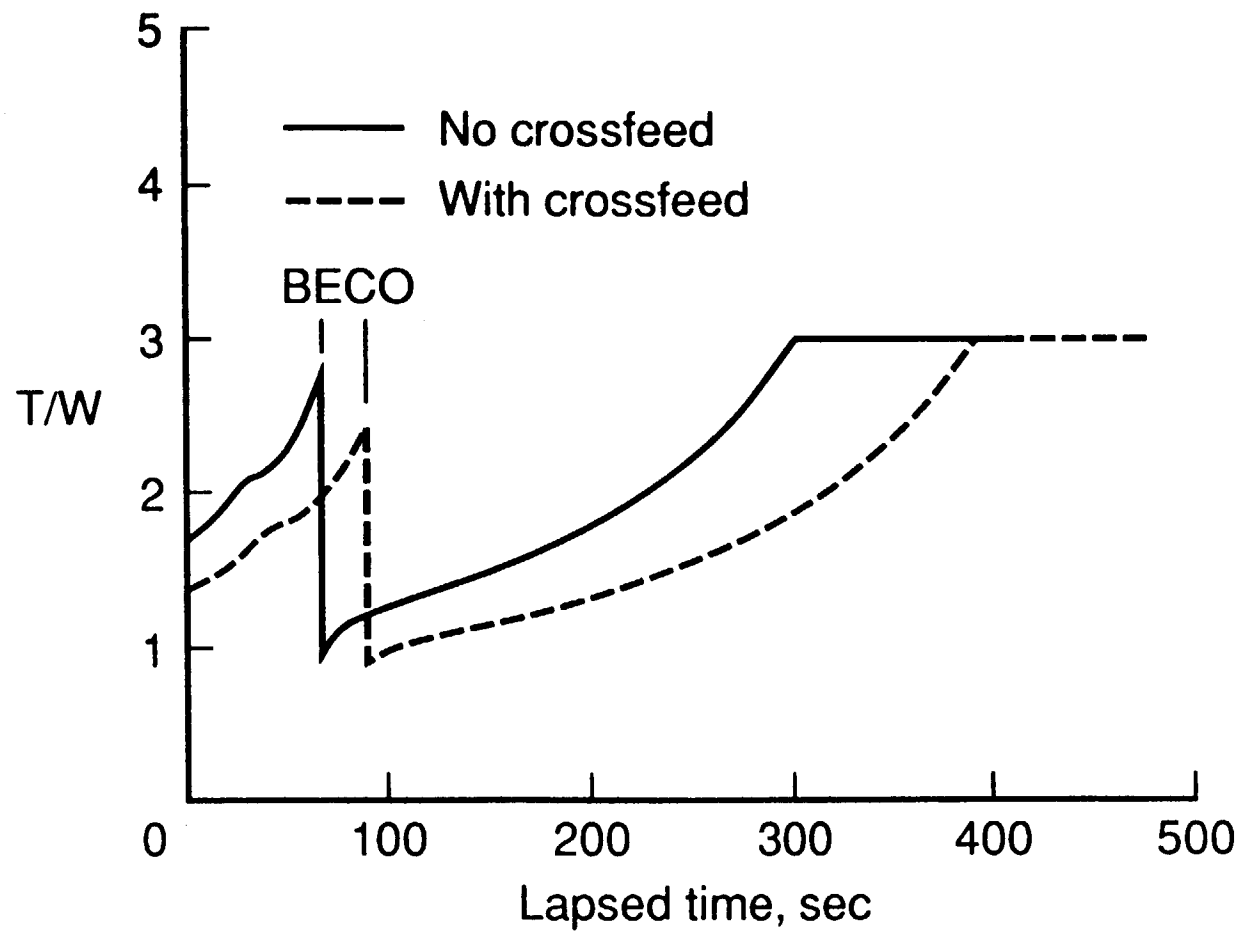
Figure 7.- Thrust-to-weight ratio versus time for liquid strap-ons.
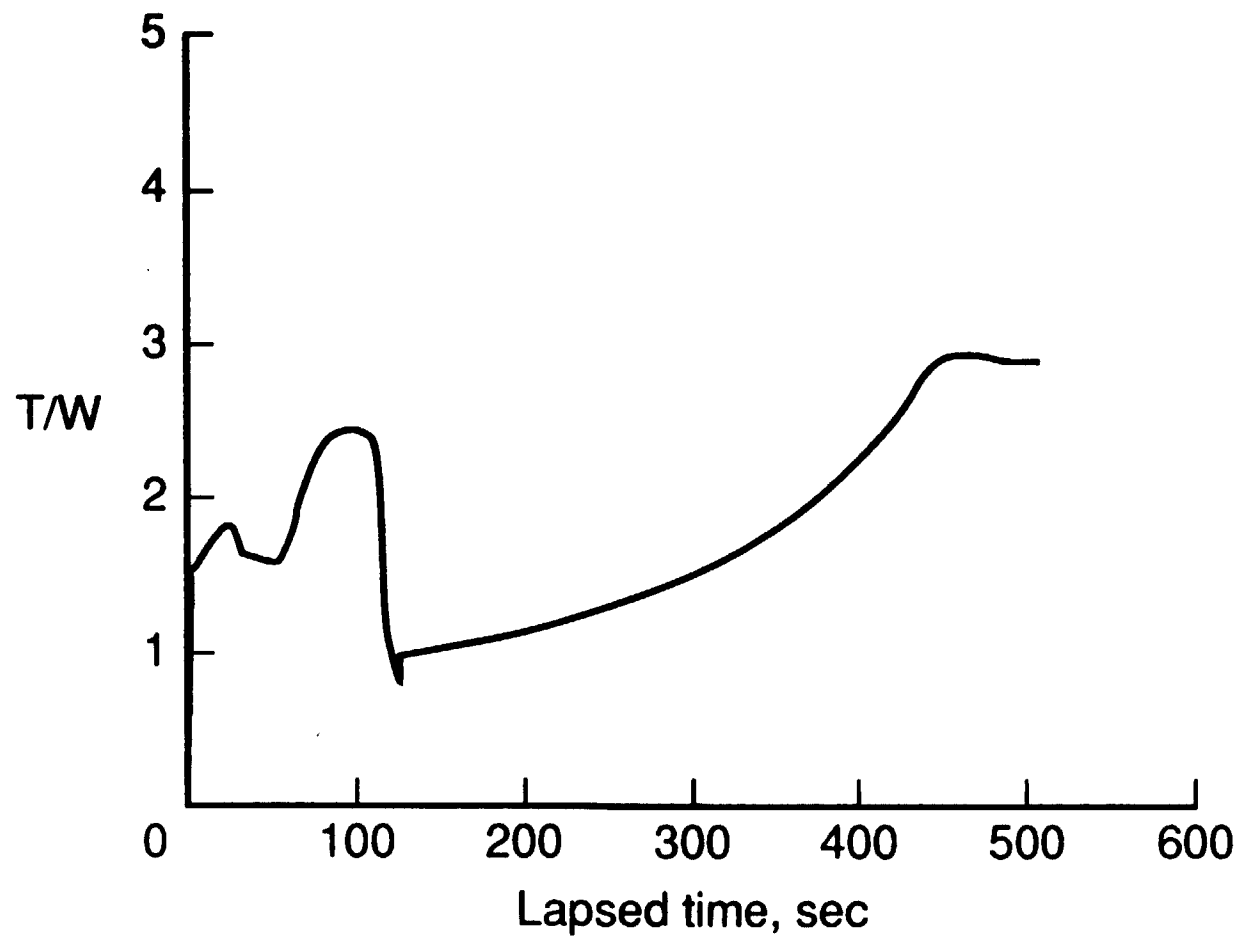
Figure 8.- Thrust-to-weight ratio versus time for the current Shuttle.
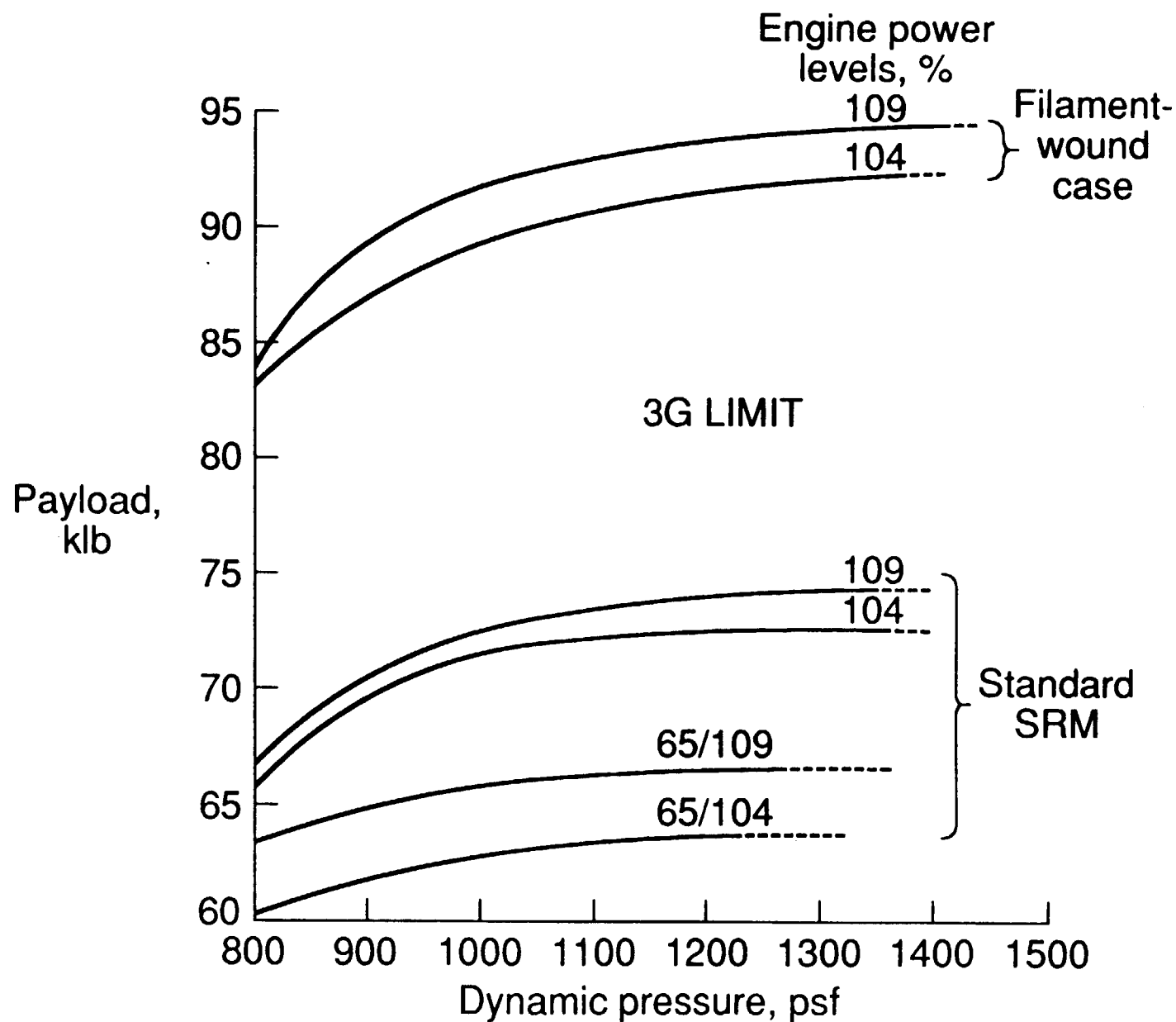
Figure 9.- Payload versus dynamic pressure for core vehicle with STM's.
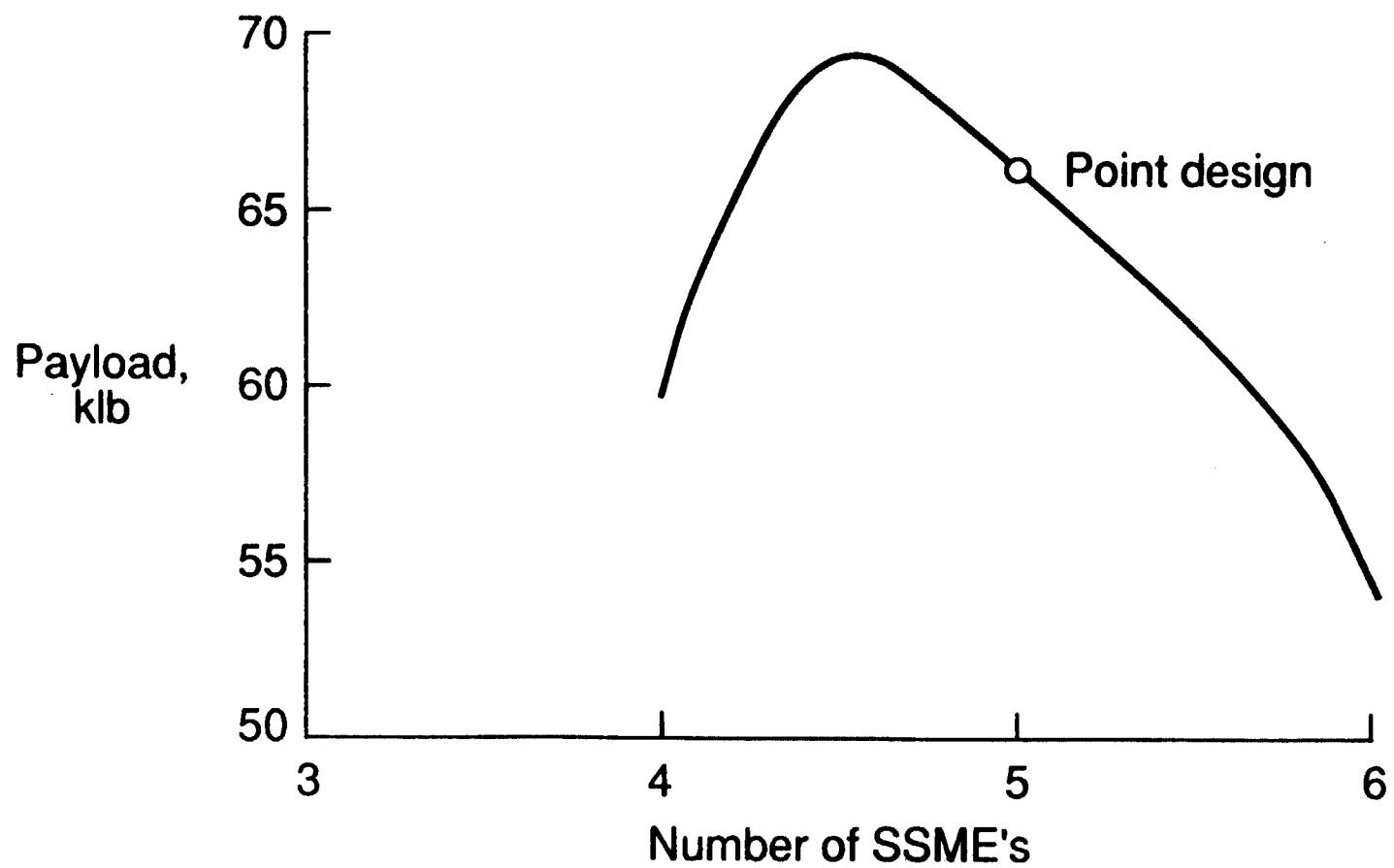
Figure 10.- Payload versus number of engines on core vehicles.
Maximum q = 800 psf and power level of 104%.

Weight
Gross = 4.8 Mlb
Payload = 160 klb

Filament-wound cases

Payload bay
30-ft dia. x 15-ft length

5 SSME's

197 ft
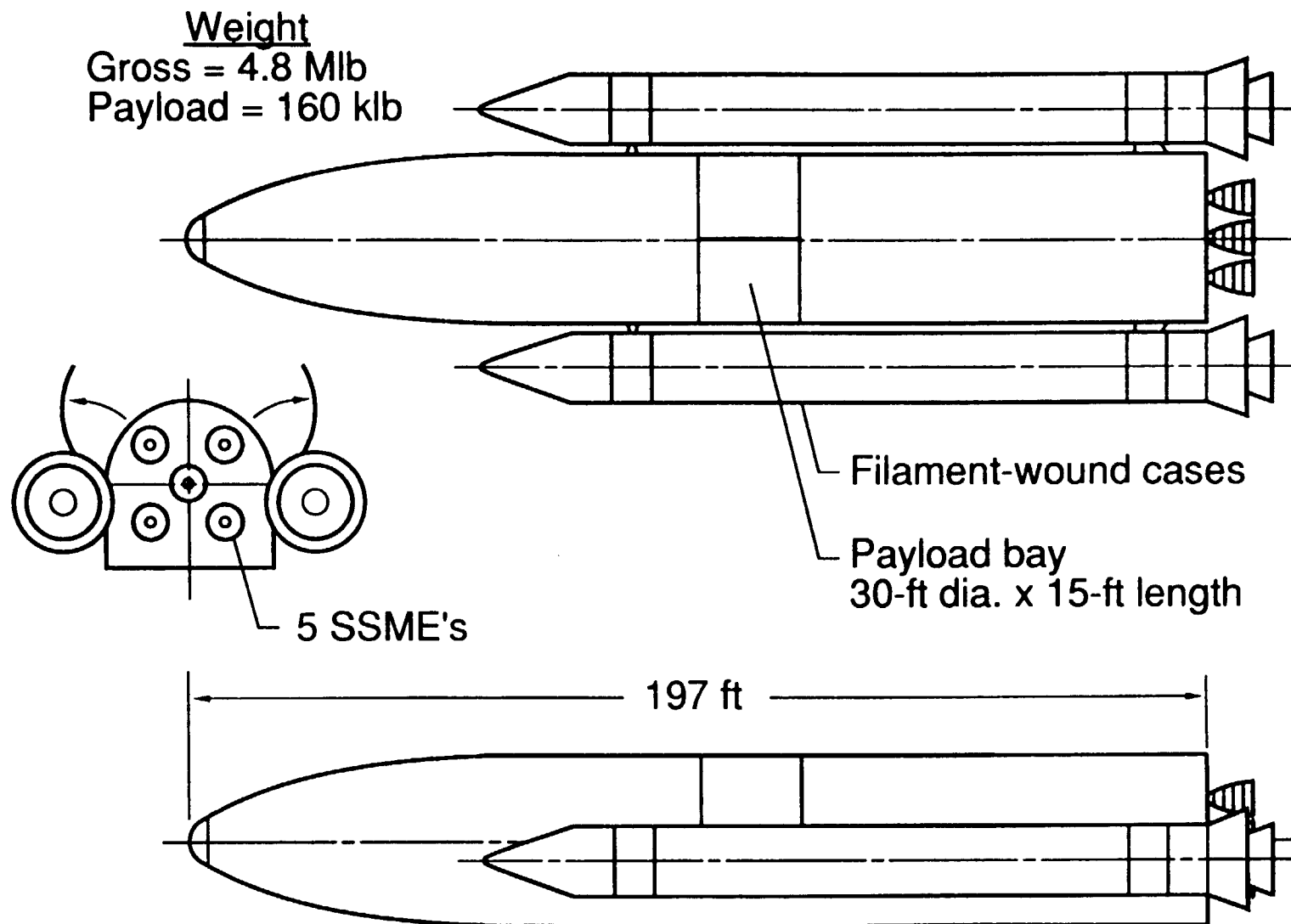
Figure 11.- Expendable core vehicle option with SRM's.

This appendix provides the individual weight allocation for each subsystem.

Table A-I. Core Vehicle Weight

	Wt, lb
1.0 Wing Group	17,867

      1.01 Exposed Wing (Includes tip fins)...... 17,522
      1.02 Carry-Thru (Integral)................. 345

2.0 Tail Group (Dorsal)	642
3.0 Body Group	107,626

      3.01 Crew Module 558
      3.02 Forebody 1,396
      3.03 Mid-Fuselage 22,594
      3.04 Aft-Fuselage 9,622
      3.05 Thrust Structure 4,494
      3.06 Body Flap 427
      3.07 Fuel 1 Tank 0
      3.08 Fuel 3 Tank 0
      3.09 Fuel 2 and 4 Tanks 48,863
      3.10 Oxidizer 1 and 2 Tanks 19,672
      3.11 Oxidizer 3 Tank 0

4.0 Thermal Protection System	42,645
5.0 Landing Gear and Auxiliary Systems	11,487
6.0 Main Propulsion System	49,432
7.0 Propulsion, RCS	6,653
8.0 Maneuver System, OMS	8,270
9.0 Prime Power	1,362
10.0 Electrical Conversion and Distribution	3,154
11.0 Hydraulic Conversion and Distribution	0
12.0 Surface Controls (All Electric)	5,551
13.0 Avionics	3,962
14.0 Environmental Control (Flash Evaporator)	1,169
15.0 Personnel Provisions (Crew of two)	900
16.0 Margin	25,601
Inert Weight	286,321

17.0 Personnel (Crew of Two) 652

18.0 Payload Accommodations 3,692

19.0 Payload Returned 65,000

20.0 Residual Fluids 1,534

       Landed Weight   357,199

22.0 RCS Propellant 2,996

23.0 OMS Propellant 53,452

24.0 Payload Discharged = Ascent - Returned 0
                                                   ————————

       Insertion Weight   413,647

25.0 Ascent Reserves 1,151

26.0 Inflight Losses 8,831

27.0 Ascent Propellant 1,918,076

     27.01 Fuel #1 0
     27.02 Fuel #2 (LH2)...................... 273,942
     27.03 Fuel #3 0
     27.04 Fuel #4 0
     27.05 Oxidizer #1 0
     27.06 Oxidizer #2 (LOX)..................1,644,134
                                      ————————

    Gross Liftoff Weight (Lb)   2,341,705
    Calculated Body Length (Ft)   197

Table A-II. Liquid Strap-on With No Cross Feed

                                                     Weight,Lb

1.0 Wing Group 5,720

     1.01 Exposed Wing 4,978
     1.02 Wing Carry-thru (wing pivot and track)   742

2.0 Tail Group (Canards Plus Dorsal)........................501

```
3.0 Body Group ......................................14,927

        3.01 Crew Module ............................  0
        3.02 Forebody ..............................429
        3.03 Mid-Fuselage ........................ 2,136
        3.04 Aft-Fuselage ........................ 1,968
        3.05 Thrust Structure .................... 4,490
        3.06 Body Flap ...........................   77
        3.07 Fuel 1 Tank (RP).....................  552
        3.08 Fuel 3 Tank .........................    0
        3.09 Fuel 4 Tanks (LH2 for Gas Generator)......1579
        3.10 Oxidizer 1 Tank (LOX) ...............3,696
        3.11 Oxidizer 3 Tank .....................    0

4.0 TPS ........................................   321

5.0 Landing Gear and Auxiliary Systems ........ 2,290

6.0 Main Propulsion System ....................23,126

7.0 Propulsion RCS ............................    0

8.0 Maneuver System OMS .......................    0

9.0 Prime Power ...............................  568

        9.01 Batteries for Avionics ...........259
        9.02 Batteries For Actuators ..........309
        9.03 APU's for Actuators ..............  0

10.0 Electrical Conversion and Distribution ........... 1,052

11.0 Hydraulic Conversion and Distribution ............    0

12.0 Surface Controls ................................ 1,173

13.0 Avionics ........................................ 1,742

14.0 Environmental Control ...........................   25

15.0 Personnel Provisions ............................    0

16.0 Margin .......................................... 5,029
                                                      _____
        Inert Weight                                   56,474

17.0 Personnel .......................................    0

18.0 Payload Accommodation ...........................    0

19.0 Payload Returned ................................    0
```

20.0 Residual Fluids 311

       Landed Weight   56,785

22.0 RCS Propellant 0

23.0 OMS Propellant 0

24.0 Payload Discharged (One half of Core Veh.Stg).. 1,224,500

       Insertion Weight   1,281,285

25.0 Ascent Reserves...233

26.0 Inflight Losses 1,555

27.0 Ascent Propellant 388,466

    27.01 Fuel #1 90,746
    27.02 Fuel #2 0
    27.03 Fuel No. #4 5,827
    27.05 Oxidizer #1 291,893
    28.0 Oxidizers #2 and #3 not used 0

    Gross Liftoff Weight (Lb)   1,671,539
    Calculated Body Length (Ft)   87

Note: One half of the core vehicle weight was added to the strap-on booster weight to obtain gross weight in the above table.

Table A-III. Liquid Strap-ons With Crossfeed

                                    Weight, Lb

1.0 Wing Group 3,103

    1.01 Exposed Wing 1,246
    1.02 Carry-thru (Pivot Assembly) 1,857

2.0 Tail Group (Canards Plus Dorsal).......................1,254

3.0 Body Group 37,199

    3.01 Crew Module 0
    3.02 Forebody 1,073
    3.03 Mid-Fuselage 7,639
    3.04 Aft-Fuselage 4,926
    3.05 Thrust Structure 4,436
    3.06 Body Flap 144
    3.07 Fuel 1 Tank (RP) 572
    3.08 Fuel 3 Tank 0

3.09 Fuel 2 and 4 Tanks (X-feed & GG-LH2).... 10,905
3.10 Ox 1 and 2 Tanks (X-feed & RP-LOX)........7,504
3.11 Oxidizer 3 Tank 0

4.0 TPS 418

5.0 Landing Gear and Auxiliary Systems 4,049

6.0 Main Propulsion 22,846

7.0 Propulsion RCS 0

8.0 Maneuver System OMS 0

9.0 Prime Power 687

10.0 Electrical Conversion and Distribution 1,170

11.0 Hydraulic Conversion and Distribution 0

12.0 Surface Controls 2,197

13.0 Avionics 2,009

14.0 Environmental Control 254

15.0 Personnel Provisions 0

16.0 Margin 6,413
                                                          ‾‾‾‾‾‾‾
            Inert Weight   81,599

17.0 Personnel 0

18.0 Payload Accommodations 0

19.0 Payload Returned 0

20.0 Residual Fluids 607
                                                          ‾‾‾‾‾‾‾
            Landed Weight   82,206

22.0 RCS Propellant 0

23.0 OMS Propellant 0

24.0 Payload Discharged (One half of Core Veh.@Stgg). 1,224,500
                                                       ‾‾‾‾‾‾‾‾‾
            Insertion Weight   1,306,706

25.0 Ascent Reserves 1,098

26.0 Inflight Losses 2,295

27.0 Ascent Propellant 805,383

      27.01 Fuel #1 99,041
      27.02 Fuel #2 61,191
      27.03 Fuel #3   0
      27.05 Oxidizer #1 288,376
      28.00 Oxidizer # 2......................356,775

      Gross Liftoff Weight (lb)   2,115,482
       alculated Body Length (ft)   126

Note: One half of the core vehicle weight was added to the booster
weight to obtain gross weight in the above table.

Table A-IV. Circular Body Core Vehicle: Dimensions and Areas

Overall Dimensions, ft

Body length 196.85
Body diameter 32.81
Wing span 132.73

Areas, ft^2

Wings, fins, and movable surfaces

    Wing theoretical plan 6,982.0
    Wing, exposed plan.................. 4,372.0
    Ailerons (one side) 83.6
    Elevons (one side)
        Inboard 183.5
        Outboard 183.5
    Vertical tail (Total profile) 1,435.0
        Rudder/speedbrake (370.0)
    Dorsal.............................. 105.5
    Side-body speedbrake 139.4
    Tip fin(one side total profile)..... 158.7
        Controller/speedbrake 73.1
    Body Flap 358.0

Body   Areas, Ft^2

    Total wetted (including base)........ 18,904.0
    Ogive to station 732 ....   4,135.0
    Ogive to station 300 (1,378)
    LH2 tank barrel section 1,931.0
    Mid-fuselage 5,826.0
    LOX tank barrel section 2,800.0
    Aft fuselage 3,390.0
    Fuselage base 822.0

Total Vehicle   Areas, Ft^2

    Planform total 10,268.0
      Body ....(5,896.0)
      Wing ....(4,372.0)
    Exposed Wetted   32,357.9
      Body ....(18,904.0)
      Wing ....(9,618.4)
      Vertical tail..................(3,013.5)
      Base .... (822.0)

                                                                Volume, Ft^3
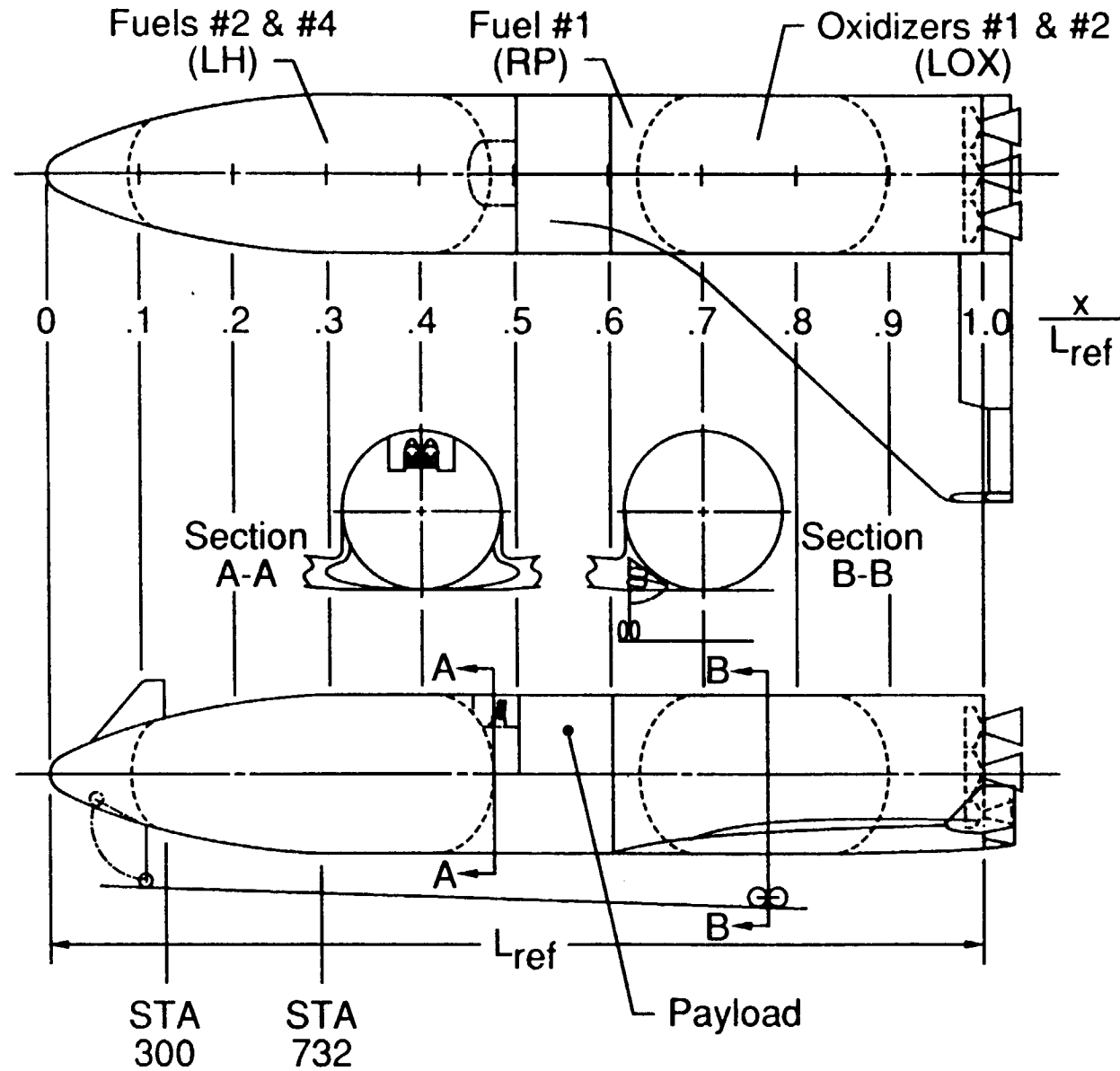
    Body volume total ....150,576 ft

Figure A-1.- Reference drawing for core vehicle geometry in Table IV.

Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TM-100603		

4. Title and Subtitle	5. Report Date
Performance of a Circular Body Earth-to-Orbit Winged Transport With Various Strap-On Boosters	October 1988
	6. Performing Organization Code

7. Author(s)	8. Performing Organization Report No.
Ian O. MacConochie, J. Chris Naftel, and Frederick W. Widman	
	10. Work Unit No.
	506-49-11-01

9. Performing Organization Name and Address	11. Contract or Grant No.
NASA Langley Research Center Hampton, VA 23665-5225	
	13. Type of Report and Period Covered

12. Sponsoring Agency Name and Address	Technical Memorandum
National Aeronautics and Space Administration Washington, DC 20546-0001	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

Various types of twin strap-on boosters have been evaluated by applying them to a core vehicle of fixed size. The core vehicle has a clipped delta wing and a simple circular body, and is equipped with five Space Shuttle main engines. The only propellants in the core vehicle are liquid oxygen and liquid hydrogen. The strap-on boosters investigated include the current Shuttle solid rocket motors with steel cases and advanced solids with graphite composite filament-wound cases. Also, two types of liquid-oxygen/hydrocarbon boosters were investigated - one pair without crossfeed to the core vehicle and one with. The payloads obtained were tabulated for various assumptions, such as power levels on the core vehicle engines, number of engines, and maximum allowable flight dynamic pressures. The payload for the core vehicle with two filament-wound Shuttle solid rocket strap-ons was 83,000 lb. The payload for two liquid strap-ons with crossfeed was 84,000 lb. The core vehicle with Shuttle solid rocket boosters strap-ons is regarded as a near term technology system.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Tanks Shuttles Propellant	Unclassified - Unlimited
	Subject Category 16

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of pages	22. Price
Unclassified	Unclassified	32	A03